

of that market. The constrained case backlog resulting from the Challenger accident is 32.5 equivalent shuttle flights, the sum of flights projected for 1986 through 1988.

The Historical Case

The historical case is a simple extrapolation of the actual trend of the past 16 years, modified to reflect the atypically high launch activity of the Apollo program in the early 1970s. The average annual demand is projected to be 10.5 shuttle equivalents. By its very nature and perhaps to its ultimate benefit, the projection does not account for plans to expand space activities. Instead it simply carries forward a real set of past activities that took place in the presence of the cost overruns, policy changes, budget shortfalls, and technical problems that mark enterprises as complex as those undertaken in space. The backlog under this projection is 28 flights.

TABLE 4. CONSTRAINED CASE DEMAND PROJECTIONS,
BY MAJOR COMPONENTS, 1986 THROUGH 2000
(In equivalent shuttle flights)

Year	Department of Defense	NASA and Other Federal Agencies	Commercial	Total
1986	2.1	3.6	1.4	7.1
1987	4.0	4.4	2.2	10.6
1988	8.4	3.5	3.0	14.9
1989	10.6	4.4	2.3	17.3
1990	9.7	6.1	3.1	18.9
1991	11.8	4.9	4.6	21.3
1992	10.1	5.5	4.2	19.8
1993	10.6	5.0	3.3	18.9
1994	8.7	4.5	2.8	16.0
1995	8.7	6.5	3.1	18.3
1996	7.3	5.5	3.1	15.9
1997	8.5	5.5	3.4	17.4
1998	8.5	5.5	3.6	17.6
1999	8.5	5.5	2.3	16.3
2000	8.5	5.5	2.7	16.7

SOURCE: Congressional Budget Office.

DEMAND PROJECTIONS AND SPACE TRANSPORTATION INVESTMENT

Demand projections provide a crude yardstick that can be used to measure the adequacy of launch capacity. While the federal government can easily adjust the annual level of space transportation supplied within a given scale of operation, the scale of operation itself (orbiters in the fleet and operating plants to produce expendable launch vehicles) requires more time and expenditures to change. As such, the current period is critical in that major decisions must be made about the ability of the United States to supply space transportation over a long period, perhaps into the next century.

While members of the space community are aware of the persistent overestimation of total launch demand, they are unanimous in their view that the question is not *if* there will be a large increase in the demand for space transportation, but *when* that increase will occur. Nevertheless, the past 15 years of U.S. space launch activity have been characterized by steady but slow growth rather than rapid acceleration. The shuttle system was to have spurred acceleration by lowering the cost of transportation, by providing a unique capability, and, more recently, by generating net revenues for NASA to permit the agency to do more for a given level of appropriations. But in the wake of the Challenger accident and revelations about the operation of the shuttle system, only the unique capability of the shuttle remains as a stimulus to growth. The current situation is far too uncertain to claim revolutionary cost advantages or net revenue gains for NASA as engines of growth for launch service demand. Therefore, it appears unlikely that the official case projections can serve as an adequate guide to future demand. Either the constrained or historical case could, perhaps, better inform federal investment decisions.

CHAPTER III

SPACE TRANSPORTATION SUPPLY

During the late 1970s and early 1980s, U.S. space transportation policy envisioned a shuttle-dominated system to serve both federal requirements and much of the worldwide commercial market. Some observers contemplated enough emerging commercial demand to stimulate the production of private launch supplies in the form of additional shuttles or expendable rockets. In this view, private launch supplies would provide the nation with standby capacity for space launches, much in the same way the U.S. merchant marine would augment the Navy's sea-lift capability in a national emergency. Foreign competition by expendable launch vehicles (ELVs) was for the most part discounted, primarily because the shuttle was viewed as far and away the lowest-cost option.

As the shuttle-dominated system was to maintain the preeminent role of the United States in the international commercial market, it was also to assert NASA's dominance as the provider of federal space transportation, replacing the preshuttle arrangement by which NASA and DoD maintained separate ELV capacities and swapped vehicles as launch needs required. Revenue flows to NASA from the commercial market and intragovernmental transfers from DoD were to have been combined with real increases in the NASA budget to help support the \$8 billion NASA contribution to the international space station. The DoD was to lose its independent launch capacity as its Titan ELV program was phased out; but DoD was to gain the benefit of lower-cost shuttle transportation.

As doubts emerged about the shuttle program, U.S. expendable launch vehicles again became a viable option for commercial space transportation. In 1983, the President explicitly recognized the relationship between the effectively subsidized price NASA offered to its private and foreign customers, on the one hand, and the prospects of "commercializing" the ELV industry on the other.^{1/} To provide a more competitive environment, the

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1. Shuttle pricing policy has never been formulated to subsidize commercial customers explicitly in that price levels have always been set to cover, at a minimum, the estimated additive cost of flights undertaken to service commercial clients. Actual costs, however, have consistently exceeded estimated costs, effectively subsidizing commercial customers.

President proposed that NASA charge a full-cost price to commercial users of the shuttle. This stimulated a debate over whether or not full cost should include past investments in the shuttle system itself or only the cost of operating it.

By 1985, perhaps in response to the perception that commercial firms would not enter a market that was growing more slowly than anticipated and was subject to competition from foreign governments, the U.S. government had begun to modify its plans for a shuttle-only system. The Air Force started the Complementary Expendable Launch Vehicle (CELV) program (recently renamed Titan IV) to provide 10 large missiles, each capable of launching the equivalent of one shuttle load into orbit.

CURRENT WORLD CAPACITY

At the time of the accident, the United States was phasing down its ELV capacity. The combination of four orbiters and the production line for the Titan rockets was supposed to provide sufficient launch capacity--more than 30 shuttle equivalents a year--to allow the Atlas and Delta rocket lines to be shut down. The accident has not affected Europe's continued contributions to world launch supplies with the Ariane vehicle, or the planned entry by Japan, China, and the Soviet Union into the market.

U.S. Capacity

In May 1986, responding to the Challenger accident, the Congress appropriated supplemental funds for fiscal year 1986 to increase Titan IV procurement by 13 vehicles to a total of 23, permitting an annual launch rate of four to six beginning in 1989. To increase U.S. launch capacity further, procurement of a medium launch vehicle (MLV) was also approved, with a target of four launches, or roughly 1.5 shuttle equivalent per year, by 1989. These actions have not only increased the volume of U.S. launch capacity but also will ensure that the United States has three independent space launch systems--two ELV systems and the shuttle fleet.

The nation's space launch capacity is the number of orbiters in the shuttle fleet and the production facilities for expendable launch vehicles. The capacity to provide space transportation services may exceed current production, scheduled shuttle flights, and ordered ELV services. The CBO estimates that, under current policy, U.S. launch capacity in 1989 will be 21 to 24 shuttle flight equivalents, divided almost equally between the shuttle

fleet and ELVs with production facilities in operation. Table 5 provides a breakdown of U.S. capacity in 1989 and illustrates the potential volume that could be added by procuring a new orbiter or by making a long-term procurement commitment for a third ELV option.

This analysis is conservative in its estimation of the U.S. capacity to supply space launches. NASA's preaccident projection of six flights annually for each orbiter is lowered to three to four flights per orbiter. Currently, all three U.S. ELV production lines--Delta, Atlas, and Titan--are open for new orders. The capacity estimates in Table 5, however, include only current plant capacity for which federal procurement commitments have been made--the Titan line and an as yet unspecified MLV producer.

International Launch Capacity

The quantity of space transportation supplied worldwide does not depend solely on its market value. Indeed, the capacity to provide launch services

TABLE 5. U.S. SPACE LAUNCH CAPACITY IN 1989 AND EXPANSION OPTIONS (In equivalent shuttle flights)

Launch Systems	Equivalent Shuttle Flights per Year
1989 Capacity	
Orbiters	9-12
Expendable Launch Vehicles	
Titan Family	9
Medium Launch Vehicle	<u>3</u>
Subtotal, ELVs	12
Total	21-24
Expansion Options	
New Orbiter	3-4
Additional ELVs	3-5

SOURCE: Congressional Budget Office.

may exceed the demand for such services for long periods of time (and may actually grow in periods of excess supply) as new public launch vehicles enter the market in pursuit of various noneconomic objectives. The requirements and plans of governments in the space transportation area, therefore, are the starting point for analyzing international supply conditions.

During the 1970s, the U.S. government supplied the entire noncommunist world with launch services. While individual payloads may have been delayed by launch vehicle problems, the supply of space transportation within the prevailing structure of technology and cost was more than sufficient to meet physical launch demand. Paying customers needed only to order their vehicle and wait for it to be produced. Institutional constraints on supply, among them the U.S. hesitancy in 1971 to launch a European communications satellite, *Symphonie*, prompted the European Space Agency to develop the Ariane rocket and permanently add to world launch capacity.^{2/} Like the United States and the Soviet Union, China has developed a launch capability as a byproduct of its military rocket program. The Japanese plan to increase their capability, but are unlikely to fly non-Japanese payloads before 1992.

Table 6 presents the CBO estimate of foreign capacity that will be available to the commercial market in the early 1990s. The commercial demand projection of four to, at best, nine flight equivalents per year in the 1990s is roughly equal to this potential supply, without any use of U.S. capacity. Although the Challenger accident has created a demand backlog that will need to be launched in the early 1990s, worldwide launch capacity should exceed commercial demand once this backlog is relieved. U.S. launchers seeking a share of this market are likely to encounter extremely rigorous price competition, a factor to be considered in choosing a U.S. supply policy.

THE SHUTTLE AND ELVS: SUPPLY ALTERNATIVES

Over the next 15 years, shuttle-like vehicles and improved expendable launch vehicles will constitute the available supply options. Both the shuttle system and the U.S. ELV capacity are assessed below to establish how each could best meet the major goals of U.S. space policy: first, to supply cost-

2. This hesitancy was based on U.S. adherence to the 1971 International Telecommunications Satellite Organization Agreement, which committed the U.S. to the Intelsat System, to which the *Symphonie* satellite was a competitive threat. See Office of Technology Assessment, *Civil Space Policy and Applications* (1982), p. 363.

TABLE 6. FOREIGN ELV CAPACITY IN THE EARLY 1990s

Foreign Supplier (Vehicle)	Equivalent Shuttle Flights
Europe (Ariane)	4-5
Japan (H-Series)	1-2
China (Long March)	1-2
Soviet Union (Proton)	<u>0-1</u>
Total	6-10

SOURCE: Congressional Budget Office.

NOTE: The Soviet Union could supply more capacity. A conservative estimate of foreign capacity, however, must recognize the political constraints limiting use of Soviet vehicles.

effective launch services to meet federal requirements, and second, to gain a share of the commercial market for public or private U.S. launch services which would require matching new capacity to market demands.

The Shuttle

Shuttle Costs. In 1985, CBO analyzed the projected costs of the shuttle system for 1989 through 1991.^{3/} The Challenger accident forces a reexamination of this data, but not the underlying cost concepts relevant to the shuttle system. These are described in the accompanying box. Three considerations stand out in the postaccident period. First, the shuttle remains a high fixed-cost system--the average cost of each flight declines as more

3. See Congressional Budget Office, *Pricing Options for the Space Shuttle* (March 1985).

flights are launched. Second, the additional cost borne by the government to procure and operate a replacement orbiter is the relevant cost standard to use in comparing shuttle costs with ELVs in serving the commercial market. Third, the fixed and variable operating costs of the system will increase as a result of the accident.

The NASA estimates that a replacement orbiter built over four years would require \$2.2 billion in new expenditures. A decision to build an orbiter must be made soon or the possibility will be precluded, as Rockwell International and the subcontracting base may shut down all shuttle production facilities. This study assumes that the funds to build an orbiter for

CATEGORIES OF COST

Cost analysis concerns three different types of cost--total, average, and marginal. The **total cost** of a service or a product is the sum of all the funds necessary to buy materials, equipment, and facilities and to pay workers and owners their wages and profits. **Average cost** is simply total cost divided by the number of units of service or product provided--for the shuttle, flights are usually thought of as the unit of output. **Marginal cost** is the cost of providing or producing an additional unit of service or product. Generally, providing one more unit changes some costs but not others. For example, an additional shuttle flight would increase fuel costs, but, unless the physical capacity of the system had been reached, it would not require construction of new buildings or orbiters. Only under special circumstances will marginal cost equal average cost. For the shuttle, as with other high fixed-cost industries, marginal costs are less than average costs for all relevant levels of service.

Cost becomes more complicated when time is introduced. Two distinctions are important: **fixed** versus **variable costs** and **short-run** versus **long-run** costs. Over many years, all the shuttle system costs may be seen as variable. Given enough time, new facilities could be built at Kennedy Space Center or Vandenberg, the fleet of orbiters could be doubled in size, or the entire program could be eliminated. The period of time in which all costs are variable is called the long-run. For the shuttle, such a period could be 20 or 30 years. The shorter the time under consideration, however, the more costs become fixed. For example, since a new orbiter requires four to seven years to construct, the cost of this resource is fixed for time periods of four years or more.

Once a period of analysis is specified, fixed and variable costs can be identified, and the total, average, and marginal costs can be estimated. Total costs are separated into total fixed costs and total variable costs. Marginal costs are then the change in total variable cost attributable to a one unit increase in the level of service.

flights in 1991 would be authorized over a six-year period, beginning in 1987. Thereafter, the replacement orbiter would cost an annual sum equal to the marginal cost of the additional flights flown by that orbiter each year. The CBO's analysis of shuttle costs estimated that the marginal cost of a 1989 shuttle flight would be \$48 million, a "base case" estimate drawn from a broad range from a low of \$32 million to a high of \$81 million (all in 1986 dollars). A 1986 study by Resources for the Future estimated a marginal cost range from \$33 million to \$70 million (both in 1985 dollars). ^{4/}

The Challenger accident will increase the marginal cost of shuttle operations, but by how much is uncertain. Before the accident, the bulk of shuttle costs that varied directly with the flight rate were attributable to the solid rocket booster, the external tank, Kennedy Space Center (KSC) launch operations, and Johnson Space Center (JSC) flight operations. The future cost of the solid rocket booster is unknown, but lower volume purchases and probable redesign undoubtedly will lead to higher costs, both fixed and marginal. If a competitive second manufacturer was introduced to supply solid rocket boosters, it is not clear whether competitive pressures to cut costs would triumph over lower volume purchases and the high up-front cost of qualifying a second source. The net result could be additional costs. Lower volume purchases could also raise the cost of external tanks. The JSC flight operations should not be significantly affected by postaccident changes, but both the fixed and variable costs of KSC launch operations are likely to increase. Finally, all CBO cost estimates will increase relative to NASA projections as the benefits of learning by doing are reflected in those projections.

The range of marginal cost estimates in the CBO March 1985 study of shuttle costs was broad enough to include higher postaccident marginal costs. For example, the base case estimate recognized that the flight rate underlying the NASA cost estimates would probably not be achieved and cost savings based on learning effects accordingly would be lower. In addition, allowance was made for simple cost escalation. ^{5/} Until such time as an independent audit of the cost of postaccident shuttle operations is under-

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4. Michael Toman and Mollie Macauley, *Commercial Policies and International Competition: The Example of Space Transportation Policy* (Washington, D.C.: Resources for the Future, 1986), p. 15.
 5. A separate Air Force study of shuttle costs, using a historical cost growth factor, estimated that operating costs would be over 40 percent higher than NASA projections, as cited in E. Blond and W. Knittle, *Space Launch Vehicle Costs* (prepared by the Aerospace Corporation for Department of Transportation, Office of Commercial Space, 1984), p. 25.

taken, a precise estimate cannot be made. However, the upper end of the marginal cost range developed by CBO in 1985 (from the base case of \$48 million to the high level of \$81 million) provides a reasonable estimate at this time.

Shuttle Flight Rate. Since the late 1970s, NASA has continuously lowered its projections of the annual flight capacity of the shuttle system. Before the loss of Challenger, many analysts outside NASA questioned the ability of the four-orbiter fleet to achieve the long-predicted flight rate of 24 per year by 1989.^{6/} This pessimism was justified by the preaccident record. As the Rodgers Commission stated, "The capabilities of the system were strained by the modest nine-mission rate of 1985, and the evidence suggests that NASA would not have been able to accomplish the 15 flights scheduled for 1986."^{7/} This analysis adopts a conservative range of future shuttle flight rates, estimating 9 to 12 flights annually by the three orbiters remaining in the fleet and three to four additional flights if a Challenger replacement is procured.

Expendable Launch Vehicles

U.S. expendable launch vehicles have developed in "families," generally consisting of an older basic vehicle suitable for smaller payloads and newer larger vehicles developed in response to increasingly heavy payloads. For example, the General Dynamic's Atlas vehicle has been produced in four different versions--E, F, H, and G/Centaur--with the early members of the family capable of lifting 3,000 pounds to low earth orbit and later versions capable of lifting 13,500 pounds to the same orbit. Two new designs under consideration, the Atlas Centaur Super G and the Atlas K, would continue to increase the lift capability of the Atlas.^{8/} Increases in ELV weight capability generally are achieved by lengthening the fuel tanks of liquid fuel main engines or by adding on solid rocket boosters. The two other families of U.S. ELVs with active or near-active production lines are McDonnell

6. For example, see National Academy of Sciences, National Research Council, Committee on NASA, Scientific and Technological Program Review, "Assessment of Constraints on Space Shuttle Launch Rates" (1983).

7. *Report of the Presidential Commission on the Space Shuttle Challenger Accident* (July 1986), vol. 1, p. 164.

8. General Dynamics, Space Systems Division, *Launch Vehicle Availability Assessment* (March 1986).

Douglas' Delta and Martin Marietta's Titan.^{9/} A Hughes Aircraft/Boeing Company response to an Air Force request for proposal would add an additional option, the Jarvis, an all liquid fuel vehicle which uses elements of the Saturn ELV and shuttle propulsion systems.

Table 7 illustrates the growth in lift capability in the three major families of U.S. expendable launch vehicles and the proposed Jarvis vehicle. The launch capabilities shown in Table 7 are based on specific launch configurations of a booster or first stage rocket--Titan, Atlas, or Delta--and an upperstage rocket--Centaur, IUS (inertial upper stage), and PAM (payload assistance module). Upperstages are used by both the shuttle and ELVs to place satellites into higher orbits. This report is concerned with the booster industry where ELVs and the shuttle are interchangeable for most satellite deployments, rather than the upperstage industry because neither national capacity nor industrial organization in the upperstage rockets industry are a major current policy concern.

Currently, the Titan IV is the only new vehicle being produced, but both General Dynamics and McDonnell Douglas have stated that they can deliver their respective new vehicles within 24 months of an order and can reach significant production rates in three to four years.^{10/} The Hughes/Boeing proposal stated that delivery of the Jarvis could take place in 38 to 42 months if the Air Force accepted its bid.

Production of ELVs and Launch Services

Supplying launch services consists of several important stages: production of key components, production of launch vehicles, integration of payloads and upperstages with launch vehicles, and the actual launch itself. The three current major U.S. suppliers of ELVs provide all these services. Ancillary services include financing and insurance.^{11/} Engines are the most sig-

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9. McDonnell Douglas manufactures the Delta rocket but has negotiated the commercial marketing and service rights to a newly started company, Transpace Carriers, Inc.
 10. Keith Mordoff, "ELV Makers Gear for Production Restart," *Commercial Space* (Spring 1986), p. 46.
 11. Problems of insurance are not covered in this analysis. Even before the Challenger accident, increasing losses and rising insurance rates had raised questions about whether federal action to assure coverage was appropriate. One alternative to direct federal intervention would be to change the distribution of risk between satellite owners and insurers. For example, owners could purchase coverage for less than the full value of their satellites. Sharing risk by creating a pool contributed to by satellite owners, manufacturers, and launch providers is also an option. New entrants in the commercial launch market, particularly the Chinese, have included very low insurance rates in their launch package in order to increase the attractiveness of their launch services.

TABLE 7. THE EVOLVING LIFT CAPABILITY OF U.S. ELVS

Vehicle	Weight to Low Earth Orbit (In pounds)	Weight to Geosynchronous Transfer Orbit (In pounds)
Atlas Family (General Dynamics)		
Atlas E	3,000	<u>a/</u>
Atlas H	4,400	<u>a/</u>
Atlas G/Stretched <u>b/</u>	8,000	3,000
Atlas G/Centaur	13,500	5,200
Atlas Super G/Centaur <u>b/</u>	14,500	6,000
Titan Family (Martin Marietta)		
Titan II	4,200	<u>a/</u>
Titan 34/D IUS	32,000	10,000
Titan 34D/Centaur D-1	32,000	16,000
Titan IV/Centaur <u>b/</u>	40,000	20,000
Delta Family (MacDonald Douglas)		
Delta M-6	2,000	1,000
Delta 3920	5,500	2,800
Delta 4920 <u>b/</u>	<u>c/</u>	3,900
Delta 5920 <u>b/</u>	<u>c/</u>	4,400
Jarvis Family (Hughes Aircraft/Boeing Co.)		
Jarvis <u>b/</u>	85,000	12,500-20,000 <u>d/</u>

SOURCES: For Atlas: General Dynamics Space Systems Division, "Launch Vehicle Availability Assessment" (March 1986); for Titan: Martin Marietta, "Commercial Titan" (undated); for Delta: Delta, "Transpace Carriers" (undated); for Jarvis: Hughes/Boeing Co., "Jarvis Launch Vehicle" (August 19, 1986).

- a. The rockets are not used in this orbit.
- b. Proposed for development.
- c. Not available.
- d. Weight depends on upperstages.

nificant component supplied by subcontractors to prime ELV producers, with Aerojet and United Technology supplying the Titan family; Rockwell International's Rocketdyne Division, the Atlas family; and Rocketdyne, Morton Thiokol, TRW, and Aerojet, the Delta. The Jarvis proposal would require Rocketdyne to restart production of the F-1 and J-2 engines developed for the Saturn program.

U.S. producers could meet easily the production levels of ELVs discussed in this analysis. During the 1960s, U.S. producers supplied relatively large volumes of ELVs for space launches and Intercontinental Ballistic Missiles (ICBMs). For example, space launches alone averaged over 50 vehicles per year between 1962 and 1969.^{12/} General Dynamics built over 100 ICBMs a year in each of two years.^{13/} Martin Marietta produced Titan II at a rate of 20 per year in building up the U.S. ICBM force, and now indicates that its current production facility could turn out 14 vehicles annually by mixing refurbishment of Titan IIs with new production of Titan 34Ds and Titan IVs.^{14/} Table 8 provides company estimates of interim and sustainable production rates, using the current production base; these represent a baseline for estimates of capacity.^{15/} U.S. prime producers of launch vehicles have indicated that the lead times involved in the overall production process are sufficient to permit the engine producers to increase their output sufficiently to meet demand.

Currently, the federal government owns and operates the facilities capable of launching ELVs: Kennedy Space Center (including the Eastern Test Range at Cape Canaveral) and Vandenberg Air Force Base (VAFB). These facilities are adequate to support the ELV launch rates in the U.S. launch capacity estimates presented in Table 5. Modest investment in additional facilities, however, might be required to increase U.S. ELV launch rates. The NASA, the Air Force, and their respective contractors could provide enough launch personnel and support to meet the levels of supply permitted by vehicle production and launch facilities. The Space Launch Commercialization Act of 1984 (P.L. 98-575) directed the Department of

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12. TRW, *Space Log 1982-1983* (1984), pp. 40-42.
 13. General Dynamics, "Launch Vehicle Assessment" (March 1986).
 14. Martin Marietta, "Commercial Titan" (undated).
 15. Vehicle production can be expanded rapidly at a relatively low cost. For example, General Dynamics estimates that retooling and removing "choke points" would permit Atlas production capacity to increase from 5 to 25 vehicles by 1990. General Dynamics, "Launch Vehicle Assessment."

TABLE 8. ILLUSTRATIVE U.S. ELV INTERIM AND SUSTAINED PRODUCTION RATES
(In number of vehicles delivered for launch)

ELV	1988	1989	1990	1991
Atlas Family	3	5	5	5
Titan Family	4	14	14	14
Delta Family	0	6	10	10

SOURCES: For Atlas Family: General Dynamics, Space Systems Division, "Launch Vehicle Availability Assessment" (March 1986); for Titan Family: Martin Marietta, "Commercial Titan" (undated); and for Delta Family: "Air Force Seeks Shuttle Alternative," *Metalworking News* (July 28, 1986), p. 1.

Transportation's Office of Commercial Space Transportation to establish a regulatory framework to permit ELV producers to launch nongovernment payloads from government facilities for a fee. No obstacle to such launches is apparent to date.

Cost and Competition. Competitive supply of launch services, particularly to the commercial market, depends on three elements:

- o Obtaining scale economies through adequate production rates,
- o Compatibility with satellite designs, and
- o Ability to provide flexible, multiple payload launches.

To a lesser extent the location of launch facilities is relevant in that the rotational speed of the earth and inclination to orbit allows a particular rocket configuration to lift more weight into orbit from an equatorial site than from a nonequatorial site. ^{16/}

The cost of expendable launch vehicles is significantly influenced by both the absolute size of an order and the annual production rate. U.S. producers evaluate ELV production ventures on a project basis and, accordingly, amortize total project costs over an entire order. This value is then reflected as an element of unit cost. This approach to cost and pricing

16. For example, Arianespace's equatorial site at Kourou, French Guiana, provides a 10 percent lift advantage for some launches relative to the Kennedy Space Center.

demonstrates an aversion to risk compared with the view taken in other manufacturing industries in which investments are made on the basis of forecasted demand rather than orders in hand. Setting aside the absolute size of a particular procurement order, the unit cost of launch services to the government declines as the annual production rate increases.^{17/} For the Delta family of rockets, each of the eight units produced would cost about 69 percent of the cost of the second unit. For Atlas rockets, this ratio would be 65 percent, and for the Titan family, 59 percent. This fall in unit costs results from spreading fixed direct production costs, overhead, and subcontractor's fixed costs and overhead over a larger production base.^{18/}

The cost of launch services includes both hardware and operational components. At an annual rate of four launches per year, hardware costs--the booster, upper stage and payload--represented an average of 66 percent of the unit cost for the major U.S. ELVs families. Operations, launch, and range accounted for an average of 21 percent of launch cost, with "other government costs" representing an average of 13 percent. Lower booster costs represented the largest part of decreasing unit costs as production increased. Launch support costs also fell significantly as the volume of launches increased.^{19/}

The published version of the Aerospace Corporation report did not disclose estimates of commercial bids developed in the study. The breakdown of cost for each class of launch service provided to the government includes the category "other government costs," however. Aerospace contractors traditionally argue that doing business with the government imposes costs above those of the commercial market. Thus, an estimate of commercial price can be obtained by subtracting other government costs from the total unit cost.^{20/} These estimates for each of the vehicles covered in the Aerospace report are presented in Table 9 for production levels of four and eight vehicles.

17. Blond and Knittle, *Space Launch Vehicle Costs*.

18. Data were unavailable to carry forward the unit cost function to higher levels of output. It should be recognized, however, that increased output eventually may require new capital investments that slow or negate the fall in unit cost. In any event, the portion of the market for launch services U.S. expendables are likely to be called upon to serve should not push output far beyond the current production base.

19. Blond and Knittle, *Space Launch Vehicle Costs*.

20. Jacques S. Gansler, *The Defense Industry*, (Cambridge, Mass., Massachusetts Institute of Technology 1980), Chapter 3.

A launch vehicle will be more competitive to the extent that it is compatible with a wider range of satellite designs. Recent failures in launch systems have led satellite producers toward designs that can be flown on both the shuttle and the Ariane rocket family. For U.S. providers considering entry into the commercial market, compatibility with the Ariane is imperative. To this end, the Martin Marietta Company has recently sought to purchase payload support equipment rights permitting payloads designed to fly Ariane to fly Titan.

In order to be competitive, larger launch vehicles must carry two payloads per flight. The lift capability within a given family may vary considerably, and individual members of different families may overlap certain payload weight classes. In general, however, the Delta is the smallest ELV; the Atlas, the mid-sized ELV; and the Titan, the largest. The payloads to be carried may be broken down into the same classes: under 3,000 pounds--Delta class; 5,000 pounds--Atlas class; and over 6,000 pounds--Titan class. The probable distribution of future payloads is skewed towards the small and medium groups, suggesting that dual launches will be a consistent element of competitive strategy. A launch system will be more attractive to the

TABLE 9. ESTIMATED U.S. ELV UNIT COSTS FOR THE
COMMERCIAL MARKET (In millions of 1984 dollars)

Vehicle and Configuration	4 Units per Year	8 Units per Year
Delta 3920/PAM	39	36
Atlas K/SGS IIA	44	37
Atlas G/Centaur D-1A	54	48
Titan 34D/Support Module	78	59
Titan 34D/IUS	121	100

SOURCE: Congressional Budget Office estimates, based on Aerospace Corporation estimates of cost to the government taken from E. Blond and W. Knittle, *Space Launch Vehicle Costs* (prepared by the Aerospace Corporation for Department of Transportation, Office of Commercial Space, 1984), p. 25.

extent that the launch dates of some payloads are flexible so that other users with tight launch time frames can be accommodated sooner. Even smaller, single payload systems may require such flexibility, in that launch delays for a particular payload or commercial targets of opportunity can require changing the manifest to win a particular bid.

U.S. competitiveness in the commercial launch market will require government procurement of ELVs regardless of whether the public sector or the private sector or some hybrid of the two ultimately delivers the services. Only the federal government can offer the volume of business sufficient to permit production rates high enough to allow cost competitiveness with foreign ELVs. Similarly, only governmental launch requirements are so large that schedule delays can be absorbed to permit the flexible launch times and the sale of services by the pound necessary for competitive supply.

PROJECTED DEMAND, CAPACITY, AND THE OBJECTIVES OF U.S. SUPPLY POLICY

The projections of demand provided in the preceding chapter can be compared with the capacity provided for by current policy and expansion prospects developed in this chapter. This assessment of the adequacy of the capacity provided by current policy depends on the view taken of future demand. The official case suggests barely adequate capacity, since even the addition of a new orbiter would only raise U.S. capacity during the 1990s to a range of 24 to 28 annual flights, less than the projected average annual demand of about 30 flights per year. Under this case, federal procurement of ELVs would undoubtedly increase, causing new capacity to be brought on-line. An increase in the size of the orbiter fleet to five might also be in order, as the backlog of shuttle flight equivalents stacked up from 1986 through 1988, is estimated at 60.

A very different view of the need for new capacity emerges if the more realistic range of demand is used as a starting point. As Table 10 shows, only in the official case would the average annual level of demand expected between now and the end of the century exceed the capacity provided by the three-orbiter fleet and the ELV production facilities that DoD procurement will keep active through the early 1990s. In the constrained case, annual capacity provided by current policy would cover 130 percent to 145 percent of average annual demand. Adding the capacity provided by an additional orbiter would increase this range to 145 percent to 170 percent. If demand were to follow the historical case path, the capacity provided by

current policy could carry 200 percent to 230 percent of annual demand, and addition of a new orbiter would increase the range to 230 percent to 270 percent of the projected annual launch requirements, dramatically above projected demand.

The backlog of demand, which actually would grow in the official case, is also more manageable under the more likely alternative views. The 30 some flight equivalents of backlog in the constrained case projection would represent three to six years worth of the excess of capacity over the annual requirements of that case with no additional capacity expansion. If demand was expanded by the three to four flight equivalents per year provided by a new orbiter, the backlog could fall to only two to three years worth of the excess of capacity over demand. Because the historical case projects a backlog of only five fewer flights than the constrained case, the relation between current capacity, the addition of a new orbiter, and the backlog would be basically the same. The urgency of the backlog could be overstated in all cases in that civilian scientific experiments, while desirable, may impose little cost to society if delayed and commercial demand might seek launch services.

TABLE 10. ALTERNATIVE DEMAND PROJECTIONS COMPARED WITH ESTIMATES OF CURRENT POLICY AND EXPANDED CAPACITY

	(In equivalent shuttle flights)			Projected Demand as a Percentage of Current Policy Capacity	Projected Demand as a Percentage of Expanded Capacity
	Projected Annual Average Demand	Estimated Current Policy Capacity	Estimated Expanded Capacity (Replacement orbiter)		
Official Case	28.5	21-24	24-28	74-84	84-98
Constrained Case	16.5	21-24	24-28	127-145	145-170
Historical Case	10.5	21-24	24-28	200-229	229-266

SOURCE: Congressional Budget Office.

Under the official case projection, new and backlogged demand would permit the shuttle capacity to be used fully and the federal volume of ELV procurements to be sufficiently large to allow a competitive U.S. offering of expendable launch vehicles to the commercial market. Under either of the more likely cases, however, a potential conflict emerges between cost-effective use of the shuttle and federal procurements of ELVs at rates sufficiently high to permit competitive commercial offerings. Extensive use of ELVs would cause the shuttle fleet to be underused, while full use of the fleet would lower ELV procurements, increasing the per unit cost of ELVs to the government and diminishing their attractiveness to the world market. In this context, the Administration's proposal to withdraw the shuttle from the commercial market could ensure the underuse of an expanded--or perhaps even the current--shuttle fleet, thereby increasing the cost differential to the government between using ELVs for its own needs and investing in an additional orbiter. These comparative costs are estimated in the next chapter.